FUNDAMENTAL ASTROMETRY - ITS PRESENT STATE AND FUTURE PROSPECTS

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The present status of the results and accuracy of fundamental astrometry is analyzed, confining ourselves, however, to the results obtained with the azimuthal, with the meridian instruments in the first place. Special attention is given to the origins of the observational errors, characteristics of the stellar catalogs of various types, astronomical constants and questions of proper motions. A survey is given of new tendencies in this field: in classical optical astrometry as well as in radio and space astrometry. Works concerning the elaboration of the new FK5 catalogue are reviewed.

The conclusion is drawn that fundamental astrometry has found its way out of stagnation and conditions are created for more intensive advance. Notwithstanding the introduction of qualitatively new methods of observation, the importance and role of the classical optical, ground-based astrometry will not be diminished in the near future - provided, however, that the accuracy of its results increases considerably. It is to be hoped that two-dimensional fundamental astrometry in the sky will develop into three-dimensional astrometry in space.

1. Astrometry is the oldest of all astronomical disciplines, fundamental astrometry having the longest history of all. The determination of the positions of celestial bodies has been practised for several thousand years already, but that work, by its very nature, cannot ever be completed. Three reasons might be put forward as an explanation, all three, however, being summarized in one - the developing course of astronomy (Teleki, 1969). First, the ever increasing number of stars, whose positions need determination. Second, the instruments, accessories, observers and methods are not perfect, hence the measured results are affected by errors, which become less as

technical perfection is approached. Third, the star positions need recurrent determinations, at different epochs, in order to study the dynamics of stellar motion. We have thus to deal with a continuing process.

In order to obtain knowledge about the motion of celestial bodies good connection is necessary between old and new observational series, whereby a certain conservative spirit is introduced into fundamental astrometry: thus to avoid new accidental and systematic errors we are recommended to preserve old instruments, old observational methods and even old observers. For instance, when composing AGK3 catalogue Hamburg astronomers have applied the same instruments and methods as those applied with the elaboration of AGK2 catalogue – thirty years earlier, although they might have applied more modern treatment.

On the other hand a continuous perfection of instruments, accessories and methods is necessary to reduce measuring errors. This is an unavoidable course, the need for more precise positions of celestial bodies growing each day.

Two conditions should, therefore, be satisfied: on the one hand it is necessary to maintain connection, as tight as possible, with the old measurements, and on the other, by introducing new methods and instruments, to increase the precision. As none of these principles can be ignored, fundamental astrometry is not in a static position but is changing and developing. True, these changes are not as fast and as conspicuous as in other aspects of astronomy, but still they are significant.

In the following we wish to give a picture of the present state and future prospects of development of fundamental astrometry, holding in mind the two principles above cited. We shall consider only those observational results and final products derived from them – stellar catalogues – obtained with the azimuthal, with the meridian instruments in the first place. We thus omit the results of photographic astrometry, this being the object of our next researches.

PRESENT STATE

2. Introduction

Høg (1974) gives the following table (Table 1) about the present state of accuracy of stellar positions. As one can see, with the classical instruments accidental errors in right ascension of $+0^{s}.016 \sec\delta$ $(-0''.24 \sec\delta)$ and $+0''.40$ in declination can be expected – and these are the values attained by the end of 19th century. The last three values pertain to the results achieved with the more perfect instruments and a considerable higher precision can be stated.

But measurements of this precision are relatively scarce and when evaluating the accuracy of the present-day catalogues we have to proceed from the classical measurements. Observational catalogues contain stars observed usually 4-6 times and an internal precision of $0^{s}.007 < \varepsilon_{\alpha} \cos\delta < 0^{s}.008$ and $0''.16 < \varepsilon_{\delta} < 0''.20$ can be expected.

To this, systematic catalogue errors should be added as well as the effect of

Table 1. Performance of modern meridian circles (Høg, 1974, p.244).

Meridian circle	Type of micro-meter	Observations				Mean errors		Arc	
		Start	Years	Nights	Obs.	$\Delta\alpha \cos\delta$	$\Delta\delta$	in α	in δ
11 m.c.'s AGK3R	visual	1956	6	–	300 000	$0^s.016$	0".35	–	–
In Bergedorf	visual	1956	6	360	41 611	0.016	0.42	2^h	60^o
In Perth	MSM*	1967	5	580	110 000	0.012	0.27	7	140
In Brorfelde	photogr.	1964	8	300	50 000	0.015	0.22	2	25
In Bordeaux	tracker	1971	-	34	1 500	0.007	0.20	4	80

*Multislit micrometer

Table 2. Average mean errors (individual, systematic, and total for different regions) of the FK4 (Lederle, 1976).

	Northern sky $\delta > -10^o$ (59%)			Southern sky $\delta < -10^o$ (41%)			Catalogue all stars		
Error:	Ind.	Syst.	Total	Ind.	Syst.	Total	Ind.	Syst.	Total
$m_\alpha .\cos\delta$	0".03	0".03	0".04	0".05	0".06	0".08	0".04	0".04	0".06
$m_{\mu\alpha} \cos\delta$	0.12	0.12	0.17	0.24	0.24	0.35	0.17	0.17	0.24
$m_\alpha \cos\delta$ 1925	0".03	0".03	0".04	0".06	0".06	0".09	0".04	0".04	0".06
1950	0.05	0.03	0.06	0.10	0.07	0.12	0.07	0.05	0.09
1975	0.07	0.06	0.09	0.15	0.12	0.19	0.10	0.08	0.13
2000	0.10	0.09	0.13	0.21	0.17	0.27	0.15	0.12	0.19
m_δ	0".03	0".02	0".04	0".05	0".03	0".05	0".04	0".02	0".04
$m_{\mu\delta}$	0.12	0.06	0.13	0.23	0.10	0.25	0.17	0.07	0.18
m_δ 1925	0"03	0"02	0"04	0"05	0"03	0"06	0"04	0"02	0"05
1950	0.05	0.02	0.06	0.09	0.05	0.11	0.07	0.03	0.08
1975	0.08	0.04	0.09	0.14	0.07	0.16	0.11	0.05	0.12
2000	0.11	0.05	0.12	0.20	0.09	0.22	0.15	0.07	0.16

the errors in astronomical constants, applied in the reduction. In this way a realistic accuracy of the fundamental coordinate system is obtained, which represents the final goal. In view of the fact that in constructing a fundamental system a number of absolute stellar catalogues are utilised one is entitled to expect a higher accuracy of that system. According to Lederle (1976) the mean error of a FK4 star, comprehending the entire sky, might be evaluated at $+0^{s}.013 \sec\delta$ and $+0''.12$ for the epoch 1975.0, while the errors of the centennial proper motions at $+0''.24 \sec\delta$ and $+0''.18$, which are certainly not small values. As can be seen from Lederle's table (Table 2), there exists a considerable difference in the accuracy of the stellar positions in the northern and southern parts of the sky.

These data are an indication that we may be misled by the given internal errors of the observational catalogues, as we expect considerable higher accuracy of general and especially of the fundamental catalogues. We see, however, that the total errors in the stellar positions, found in the FK4, is on the average $+0''.1$ in both coordinates, not a small amount in view of what an accuracy is expected – certainly of the order of $0''.01$ – say in the research into the motion of the Earth's poles. But even this accuracy is found with only a restricted number of stars (1535), the errors of other catalogues being considerable higher.

The question therefore arises what are the sources of these errors and how to reduce or eliminate them! It is evident that, first of all, those effects appearing in the basic observational results should be considered, because it is on them that accuracy of the final results depends: the catalogues and astronomical constants.

3. Origins of the observational errors

We shall divide these into four groups, depending upon where they originate: instrument, observer, surroundings or methods.

3.1. For a long time astrometry has been considered the „most mathematical" branch of astronomy, and the astrometrists have received essentially mathematical education. It is therefore no wonder that, owing to this, the instrument was considered a geometrical body: two axes and telescope. But it turned out that the main origin of errors lay just in this conception. The instrument is not merely a geometrical body, but physical also. Earlier belief that by multiplying the observations the instrumental errors might be reduced proved false. The advance has been achieved only as full attention has been paid to the study of the instrument's properties and, on that basis, to the elimination or reduction of those influences.

The most prominent among these effects is doubtless that due to the temperature. Continuously variable temperature fields around instrument are created, causing changes of the general characteristics of the instrument.

In order to show how sensitive an instrument can be to temperature changes, we take the level as an example. It is well known that a precision higher then $\pm 0''.1$ is required from a level. This, however, cannot be achieved, not only because of the imperfection of the level itself, but because of the temperature effects as well.

According to Drodofsky (1956) a difference in temperature of 0°01 C between the two ends of the level tube brings about a shift of the level bulb towards the warmer end of 0".1. Levels are partially protected against temperature effects, but in practice errors of the order 0"1 are possible.

One of the important problems is the flexure of the instrumental parts (Zverev, 1950; Atkinson, 1967; Rusu, 1974), in particular that of the tube under its own weight, aggravated by the ever changing temperature field. Inexplicable changes of this kind have been reported with every instrument, i.e. changes are produced which are a combined effect of many factors, „pure" flexure being one of them. What importance one should attach to this problem is convincingly shown by the examination of the changes of the horizontal flexure component carried out by day (Kosin, Mijatov, 1972). Changes of the order 0".5 - 0".6 are found, a convincing proof of the importance of this effect in the determination of star declinations. Some authors have tried to derive corrections to the flexure values due to the temperature, but there is evidence that a substantial improvement has not been achieved. As is well known, the problem is in the existence of pronounced temperature gradients of which little is known.

Speaking generally, various temperature corrections, usually derived for many instrumental parameters cannot clear observational results from these effects. This is impossible because one is not able to predict the final effect of the temperature processes in the instrument's body. This applies especially to large astrometrical instruments, where even a small temperature effect might produce large errors.

The characteristics of the instruments are changing, accordingly the coordinate system of stellar catalogues deduced from observations with these instruments is also changing. Zverev (1974, 1976) is therefore right in pointing out that the study of instrumental systems is a principal task of astrometry.

Quite independently of temperature effects, the imperfection of an instrument's parts and that of the complete instrument constructed from them, are also creating problems. Let us have a look at the influence of the optical system, micrometer, circle, axis and the instrument as a whole.

3.1.1. The position of the objective in the tube and mutual position of the both objective components are subject to various changes (Suharev, 1954), capable of bringing about considerable deflexion of the image of the order of 0".01 and more (Bagil'dinskij, et al., 1972). Changes in the tube and thermic factors are affecting the optical system, altering thereby flexure, collimation and star position. For instance, Høg (1972) has noted a systematic error of 0".02 in collimation, attributing it to the effect of lateral flexure and of errors having their origin in the objective. Harin (1970) has indicated on the basis of observational data, a dependence of the line of sight change on the anomalous position of the objective.

3.1.2. Table 3 exhibits the possibilities of meridian instruments' micrometers according to Høg (1974). The results are derived theoretically, and correspond to those expected, under the conditions of average seeing, with a telescope of 20 cm aperture and a 40^s duration of observation. As can be seen the mean error (in right ascension) of a single measurement with a classical optical micrometer is 0".24, a large value indeed.

Table 3. Performance of meridian circle micrometers under comparable conditions (Høg, 1974, p. 245)

Micrometer	m.e. (in R.A.)	Limit mv	Cathode	Autocol-limation	Daytime objects
Visual	0"24	10	-	yes	yes
Photogr.,Brorfelde	0.22	11	-	no	no
MSM, Perth	0.18	10.5	'S'	yes	-
MSM, proposed	0.15	11.5	'S'	yes	yes
Tracker, Bordeaux	0.10	9	'S'	no	no
Tracker, Klock	-	10	S20	yes	(yes)
Optimum photoelectric	0.13	15.2	'S'	yes	yes

3.1.3. According to Høg (1974) there are four principal problems connected with classical declination circles: their quality, illumination, recording – measuring and division errors. Old metal circles are unsuitable to provide for contrasting divisions, consequently the mean error of a reading, including division errors of a circle with four microscopes, is not under ±0"15 (Høg, 1972). According to Suharev (1954), optimal precision of a single circle reading is ±0"05, hardly to be attained even in the future. There are many divisions on a graduated circle, making their investigation difficult, and the errors of determination of the circle division errors are appreciable. The precision of circle graduation with modern equipment is 1 - 3 microns, which is equivalent to a 0"7 - 2"0 shift of the divisions on a circle of 60 cm diameter, whereas the accidental error of the division cutting is ±0"20 (Podobed, 1968 a). A glass divided circle has been manufactured for the six-inch transit circle of the U.S.Naval Observatory, subsequently covered by a gold film (Klock, 1976). An excellent contrast has thereby been achieved, leading to a considerable improvement in the repeatibility of the automatic circle scanning system: the previous value of 20-30 microdegrees is now reduced to 10-15 microdegrees.

3.1.4. The problems connected with the axes of meridian circles and transit instruments are identical with those of their pivots. In the past there were technical obstacles in manufacturing the pivots and in relating them correctly to the rotational axes, but now the removal of these shortcomings should be possible. Nevertheless these effects continue to be present as function of the axis position in its supports (clamp effects), the origin of which is to be sought, among others, in the axes. Differences up to order of 0"1 are reported in the results obtained in both positions of instrument. The parts played by both axes of the vertical circles are prominent – position variations of the vernier plate axis is being controlled by the levels. but there is much uncertainty in the derived inclinations of these axes (variation of these inclinations during the night is a proof.) In deriving declinations with meridian or vertical circles the position of the horizontal axis is usually neglected, considering this as being of minor importance - it has been shown, however (Teleki, Mijatov, 1972), that this effect might cause an uncontrollable shift with respect to the microscope frame, which in turn, through the variable zenith point value, is causing errors in the calculated zenith distance value (errors of the order of 0".1 might be expected).

3.1.5. In the every day routine intrumental parts are investigated according to some laboratory method, their characteristics are established and the astronomer is prepared to believe that he has determined the characteristics of the instrument as a whole. But an unpleasant surprise comes when the observation of stars reveal the imperfection of the instrumental complex. The basic problem is in the assemblage of the instrumental parts in one whole (Suharev, 1954). The Belgrade Vertical Circle might be taken as an example: an insufficient stability of the optical and mechanical parts of the tube has been reported (Teleki, 1970), it has also been found that after the reversal of the instrument around its alidade axis (stars are observed in both clamps positions) an interval of three minutes is necessary before the instrument has reached equilibrium (Usanov et al., 1976), etc. All this was reflected in the precision of measurement (up to 1") and only after total reconstruction has it been possible to reduce or eliminate these negative effects.

3.2. Maskelyne established, as early as the 18th century, a difference in the results of two observers exceeding the limits of accidental errors. This has its validity at the present time also, especially at the observations of the Sun and planets. Differences in the results between observers amounting even to a few tenths of arc seconds are found with classical instruments (Zverev, 1954). Moreover, personal errors are variable not only from year to year, but in the course of one night as well. It is therefore not necessary to emphasize particularly the importance of such effects upon the catalogue results.

3.3. The effects having their origin in the surroundings may be grouped as follows: soil drift, swinging of the instrumental pillars, changes of the instrument's physical state and variations of the refraction effects.

The first two groups are generally of minor importance, their effects being mainly insignificant (the soil, as a rule, is stable) or even elimimated (by good foundations of the pillars). This viewpoint is of course acceptable provided there were not any considerable motion of the soil or pillar. But in case such a motion has been stated steps should be taken of an obligatory reclamation. It is necessary, for an absolute catalogue, that the position of the instrument should remain unchanged during the whole observational program, whereas when differential observations are in question, the requirement for stability extends over only one night. According to experience gained so far this can be attained, but it does not mean that the whole problem is put off the agenda.

Particular difficulty is presented by the study of the instrument's physical state under the influence of various factors such as housing, atmospheric conditions, observer etc. It is difficult to say anything about the real values of these effects, but we know from experience that they cannot be accounted for and that only preventive measures (thermal protection, construction as simple as possible etc.) can provide some help.

The refraction of the light ray in the Earth's atmosphere is a phenomenon which must be taken into account – especially when observations expected to be of high precision are in question. It can be estimated (Teleki, 1974a) that the present uncertainty in the value of the astronomical refraction, according to the formulae used, is of the order of some hundredths of seconds of arc – increasing with the zenith distance. If the density field is extensively disturbed, then even greater values follow from the estimation. The reasons for this state are to be sought in a number of physical and meteorological factors (Teleki, 1974b), as well as in the housing, terrain etc. (Teleki, 1969b). When connecting the catalogue systems of various observatories, regional characteristics must be also taken into account (Teleki, 1977).

Refractional disturbances are appearing not only with the star observations, but with many operations connected with the use of instrument such as: reading of the meridian mark positions, determination of flexure and collimation (by collimators). For instance, when determining the value of the horizontal flexure component, Mijatov (1972/3) has estimated a refractional deflection between two collimators amounting to 0".2.

3.4. It is possible to discuss the errors arising in almost every method of observation and reduction. There are no methods common to all observatories in the details of making the observations or of their treatment. The fact that each catalogue in its introduction contains a description of the measurements and the calculation is eloquent in itself. The methods applied are similar, but their differences can substantially influence the final results. It is extremely difficult to estimate what final errors will be preserved by a specific method, because there is no reliable basis with reference to which we could draw a convincing conclusion. Mathematical schemes are not capable of comprising all the influences – it has been shown earlier that these are heterogeneous and variable – i.e. there are no such methods by which all principal effects might equally well be eliminated. That is why there are so many discussions and researches, but one should not forget that we are dealing with small (at least relatively small) quantities, which are very difficult to detect.

Among the greatest difficulties in the data treatment is smoothing. Observational data are naturally different among themselves and that is why it is difficult to derive final results. In order to facilitate it, i.e. in order to diminish mean errors in the final results – we resort to smoothing. There then appear difficulties, because we have to do with rather formal, mathematical smoothing, leading to a reduction of mean errors of results, but most frequently they falsify the final results (one example: smoothing of the declinations obtained from upper and lower culminations).

4. Astronomical constants, observational catalogues

4.1. Astronomical observations of stars are performed from the Earth's surface, from a rotating planet, which at the same time is revolving around the Sun. Accordingly, the data, as they are obtained with the instrument, bear a mark of the place and time at which they are made. In order to be able to compare such values, they must first be referred to the Sun's centre, an operation for which exact values of the astronomical constants are necessary.

The observational catalogues contain system of stellar coordinates, obtained with the same instrument and within the same series of measures. There are absolute catalogues (constituting their own co-ordinate system) and relative catalogues (with coordinates referred to some given system), depending upon which observational method was used. Observational catalogues contain mean positions (usually right ascensions α and declinations δ) referred to the same equator plane and the same vernal equinox point (corresponding as a rule to the origins of Besselian years as for instance: 1900.0, 1950.0 etc.). These mean α and δ are obtained from several (usually 4) apparent coordinates derived from observations. The latter are converted into mean coordinates, from which, in turn, a general mean value is calculated. Each catalogue contains a mean time of observation for each star - this is the epoch of observation.

To make possible connection of absolute catalogues, observations of the same selected objects are being carried out - as for instance the Sun and the planets - and on the basis of differences between the calculated and observed positions corrections to the catalogue are applied whereby it is reduced in one uniform system.

We see that the catalogues are a combined product of empirical and theoretical work.

4.2. It is not necessary to emphasise in particular that catalogue accuracy depends largely upon reliability of the astronomical constants (Fricke, 1965). Let us cite this example: there have been two revisions of Bradley' observational data, gathered in the period 1750-1762. The applied constants only have been changed in the two calculations. After Auwers' calculation the accuracy of Bradley's observations has considerably been enhanced: 1.75 times in α and 1.4 times in δ (Bakulin, 1949).

At the present, astronomical constants as adopted by the International Astronomical Union in 1964 (Trans.IAU, **12B**, 1965,p. 94), are in current use. There are three groups of constant: defining, primary and derived ones. The ephemeris second and the Gaussian gravitational constant belong to the first group of constants. Primary constants are the following: astronomical unit, light velocity, Earth's equatorial radius, dynamical form-factor for Earth, geocentric gravitational constant, ratio of the masses of the Moon and Earth, sidereal mean motion of Moon, general precession in longitude, obliquity of the ecliptic and nutation constant. Out of these ten primary constants 12 derived constants are calculated (solar parallax, aberration constant, Earth's flattening factor etc.).

An advantage of this system is presented by its fixing the limits within which true values of the primary constants are to be sought. For instance the adopted value of the obliquity of the ecliptic is $23^{\circ}\ 27'\ 08''.26$, but its true value is somewhere between 23° 27' 08".16 and 08".36. The constant of the general precession in longitude adopted for the tropical century (1900) is 5025".64, but it is stated that its true value is between 5026".40 and 5026".90.

It is at once naticeable that the adopted value of the precession constant lies outside of the possible probable limits. This is a consequence of the fact that in 1964 the previously adopted value of the precession has not been changed, even though it has been well known that it needed a substantional positive correction. The question remains, however, what the real value of that correction is (Kulikov, 1969; Fricke, 1972; Zverev, 1976).

Besides the precessional constant, in 1964, for justifiable reasons, the value of the obliquity of the ecliptic, the constants of nutation and the planet masses have also been left unchanged – they still are such as they have been given by Newcomb (Kulikov, 1969).

Some progress in this field has been achieved in 1976, the year of the adoption of the „IAU (1976) System of Astronomical Constants" by the IAU (IAU Trans., **16B**, 1977), to be applied in the ephemeris from 1984 onwards. Almost all constants are changed, among others that of precession, the latter having been the subject of prolonged discussions and having attracted particular attention (Zverev, 1976; Fricke, 1977). New value of the general precession in longitude, for a Julian ephemeris century (36525 days), for the standard epoch 2000, is 5029".0966, while its real value lies somewhere between 5028".95 and 5029".25. Appropriate expressions are given for the computation of the precessional values (Lieske et al., 1977).

The new system embraces: defining, primary and derived constants. The Gaussian gravitational constant belongs to the first group, while the speed of light, light-time for unit distance, equatorial radius for Earth, dynamical form-factor for Earth, geocentric gravitational constant, constant of gravitation, ratio of mass of Moon to that of Earth, general precession in longitude (per Julian century, at standard epoch 2000), obliquity of the ecliptic (at standard epoch 2000) and nutation constant (at standard epoch 2000) belong to the second group. Derived constants are: unit distance, solar parallax, aberation constant (for standard epoch 2000), flattening factor for the Earth, heliocentric gravitational constant, ratio of mass of Sun to that of Earth, ratio of mass of Sun to that of Earth+Moon, mass of Sun. We have new values for planetary masses too.

The progress acomplished is best measured by the substantially narrowed limits within which the real value of a given constant is placed. The span between limiting values of some constants is reduced by a factor of several hundreds (400 times for the speed of light, 1000 times for the unit distance, 1000 times for the heliocentric gravitational constant, etc. respectively), but it is not small with other constants either (constant of precession 1.7 times, solar parallax 33 times, etc.).

Even though the 1976 system leads to a considerable improvement of accuracy of astronomical constants, the presence of the „vicious circle" is continues to be felt: the astronomical constants are incorrect as a consequence of the incorrect astrometrical measurements, and these in turn are incorrect because astronomical constants are incorrect. Nowadays, however, the accuracy of the astrometric results is to a lesser degree dependent upon the accuracy of astronomical constants, because there being other, more pronounced sources of errors (instrument, surroundings). The least one is entitled to state is that the precision enhancement of the observational data will result in an enhancement of the reliability of astronomical constants.

4.3. In Chapter 2 we have pointed out the present day errors of the observational catalogues, but taking into account all possible instrumental and other effects (chapter 3) they become quite understandable.

The true quality of a given catalogue could be evaluated if we were able to establish the precision with which the catalogue system represented an ideal celestial coordinate system. In that case it would be possible to determine systematic corrections, reflecting the deformities of that system in a given sky zone and as a function of given physical parameters (apparent magnitude, spectral type). The following idealized relations, giving systematic discrepancies in right ascension and declination (α and δ), might be written:

$$\left.\begin{aligned} \Delta\alpha &= \Delta A + \Delta\alpha_{\alpha} + \Delta\alpha_{\delta} + \Delta\alpha_{m} + \Delta\alpha_{sp} \\ \Delta\delta &= \Delta D + \Delta\delta_{\alpha} + \Delta\delta_{\delta} + \Delta\delta_{m} + \Delta\delta_{sp} \end{aligned}\right\} \quad (1)$$

where: ΔA and ΔD are corrections of the positions of (vernal) equinox point and equator respectively; $\Delta\alpha_{\alpha}$, $\Delta\alpha_{\delta}$, $\Delta\delta_{\alpha}$ and $\Delta\delta_{\delta}$ – errors distorting particular portions of the coordinate system; by **m** are denoted quantities dependent upon apparent magnitudes and by **sp** those dependent upon spectral type.

Speaking rigorously, it is impossible to determine these quantities, as there exist no faultless reference system. The only possiblity offered to judge about the characteristics and values is therefore the comparison of several catalogues.

There are several such comparisons, but we are going to cite two of them, which, in our opinion, in the best way represent the present state.

Van Herk and Woerkom (1961) have studied the systems of various Washington stellar catalogues. They found that the differences of systematic errors in the latest catalogues were within the limits:

$-0''.08 < \Delta\alpha_{\alpha} \cos\delta < +0''.07$
$-0.20 < \Delta\alpha_{\delta} \cos\delta < +0.08$

$-0''.07 < \Delta\delta_{\alpha} < +0''.08$
$-0.13 < \Delta\delta_{\delta} < +0.30$

Their suprising conclusion is that systematic differences between Washington, Greenwich and Paris catalogues from the period around 1860 are of the same order. This would mean that there had not been any progress in the reduction of catalogue systematic errors in the last 100 years.

Gliese (1966) has investigated this problem in more details, analysing differences between various absolute observational catalogues. His conclusion is less pessimistic: there is an obvious improvement in the values of the type $\Delta\alpha_{\alpha}$ and $\Delta\delta_{\alpha}$ last century, while the same cannot be said of the values $\Delta\alpha_{\delta}$ and $\Delta\delta_{\delta}$. The values $\Delta\alpha_{\alpha}$ are nowadays twice as small as they used to be 60 years ago. In $\Delta\delta_{\alpha}$ the improvement is

60%. At the same time the stagnation in $\Delta \delta_\delta$ is demonstrated by the following facts: the dispersion between the catalogues, observed in the period 1840-1900 is $\pm0''.113$, in the period 1900-1920 is $\pm0''.116$ while in the period 1920-1960 is $\pm0''.103$. The situation has in fact remained unchanged.

The two investigations have been carried out 10 to 15 years ago, but the conclusions preserve their validity up to date, as the observational errors, in general, have not been substantially reduced in the meantime (Van Herk, 1972).

Taken separately, the most important are the errors of the type $\Delta \alpha_\delta$ and $\Delta \delta_\delta$ (Podobed, 1968b), having their origin in the instrument. It is to be assumed that $\Delta \delta_\delta$ are caused by the flexure, circle division errors and the calculated refraction. $\Delta \alpha_\delta$ are caused by the pivots irregularities, lateral flexure, lateral refraction, changes in the collimation and in personal errors. The other two errors ($\Delta \alpha_\alpha$ and $\Delta \delta_\alpha$) are considerable less, and they are caused by the changes of the observational condition during the year and especially, during the night, the changes of the air temperature being the most important. The existence of $\Delta\alpha$ m and $\Delta\delta$ m in the visual observations might be attributed to the personal errors with the remark that $\Delta\delta$ m might, from the practical point of view, be neglected. The photographic catalogues are affected by the errors $\Delta\alpha$ m, $\Delta\delta$ m as well as $\Delta\alpha$ sp , $\Delta\delta$ sp.

It is difficult to give the real values of the errors just enumerated, because they vary from one catalogue to another. Apparently the most important are $\Delta \delta_\delta$ amounting up to 2" (Zverev, 1950). $\Delta \alpha_\delta$ are not as significant, but they easily attain several tenths of arc second.

A particular difficulty is met when determining the amount and nature of ΔA and ΔD (Podobed, 1968c; Fricke, 1972). The entirety of right ascensions is corrected by ΔA, whereas this is not the case with the declinations when ΔD is in question. The observed declinations values are corrected towards the pole, the corrections being derived from the observations of the circumpolar stars at both culminations. As a result, good internal accordance in the polar regions is obtained, but this is gradually less the case as equator is approached (Zverev, 1976). It is therefore considered that ΔD is a correction to be applied in the equator region, its value fading until it vanishes at the pole. This is the prime problem: how to apply the obtained corrections. One should bear in mind that the equator corrections are transforming an acute-angled coordinate system into rectangular one making thereby the application of this correction obligatory, whereas the knowledge of the precise position of the γ point is not always indispensable (Fedorov, 1974a). The second problem is how to determine the needed values.

Duma (1975) has recently analised the methods and results of the determination of ΔA and ΔD (i.e. declination correction $\Delta \delta_0$) of some catalogues and has set forth the problems very clearly. It is suprising that, in spite of fact that the observations of the Sun are affected by a number of accidental and systematic errors, these observations yield the surest corrections ΔA – according to the mutual accordance of various determinations of ΔA the following order is obtained: Sun, Venus, Mercury, Mars, Jupiter, Vesta, Ceres, Juno and Pallas, while the order according to the internal precision is: Moon, Sun, Venus, Mercury, Mars, Vesta, Ceres, Eros, Nemausa, Pallas and Juno. The conclusion is imposed that the precision of the determination of ΔA is mainly dependent on the distance of the particular body from the Earth. As far as the determination of ΔD ($\Delta \delta_{\circ}$) is concerned, the situation is rather more difficult: it is impossible to evaluate true amounts. New researches are necessary, and first of all more extended (several dozen years) observational series of measures.

Similar problems appear in the determination of the systematic catalogue errors in the equator zones if Sun, Moon, planets and minor planets are used (Duma, 1975; Orel'skaya, 1975).

4.4. Since the 1960s the Danjon astrolabe is being used in the time and latitude services, but it soon became evident that observations with this instrument could profitably be applied to the determination of declination and right ascension corrections. The first such catalogue was issued by Guinot and his associates (1961) and a comparison (Guinot, 1961) showed its high precision, comparable even to that of the FK4.

From 18 separate catalogues, observed with astrolabes, Billaud (1976) has formed a general catalogue. The coordinate corrections are referred to FK4. 1139 corrections of the $\Delta\alpha$ type are deduced with the mean error $0\overset{s}{.}004$, while $\Delta\delta$ are given with a mean error of $0\overset{''}{.}07$. Systematic differences between this catalogue and FK4 are stated in both hemispheres: up to $0\overset{s}{.}010$ in right ascension and $0\overset{''}{.}15$ in declination. It is evident that Billaud's catalogue is suppying highly accurate and useful data.

As a result of investigations of Débarbat (Débarbat, Kovalevsky, 1963; Débarbat, 1966) it has been found that this instrument might be used for planet observations also, and consequently an international coordinated action under her direction, for the determination of the planet positions, has been set up. As can be seen, the precision of the observation of planets and stars is equal – a favourable circumstance, and at the same time this precision is not inferior to that attained with the meridian circles and astrographs.

The introduction of the astrolabe into fundamental astrometry represents a great contribution, the good qualities of this instrument yielding at least as good a precision as that obtained with the classical instruments. What is however reducing the importance of the Danjon astrolabe is, first of all, its limited light power (only stars brighter than 6 magnitude are observable), and furthermore, observations from the same observing station are limited in altitude. To these difficulties inherent in the astrolabic method as such, should be added: the values are dependent upon 3 unknowns and it is therefore difficult to compare coordinates with each other.

5. Derived catalogues

By the term „derived catalogues" we understand catalogues compiled from several observational catalogues with different instruments and at different times. If catalogues constructed in this way, posses coordinate system of their own (i.e.primarily derived on the basis of absolute observational catalogues) they are called fundamental catalogues. But most of them derived catalogues are related to some of the known systems, giving thereby coordinates in the system of that, usually fundamental,

Table 4. Average mean errors (i-individual, s-systematic and t-total in different declinations) of the FK4 (Lederle, 1976). Unit: $0''.01$.

Error	Epoch	Declinations																				
		+75°			+50°			+20°			0°			-20°			-50°			-75°		
		i	s	t	i	s	t	i	s	t	i	s	t	i	s	t	i	s	t	i	s	t
$m_\alpha \cos\delta$	Mean	2	2	3	3	5	6	3	3	4	3	2	3	4	3	5	7	6	9	5	14	15
$m_{\mu\alpha} \cos\delta$	epoch	9	14	16	11	15	19	13	11	17	14	9	16	17	18	25	30	26	40	30	36	47
$m_\alpha \cos\delta$	1925	2	3	4	3	5	6	3	3	4	3	2	4	5	3	6	7	6	10	7	14	16
	1950	4	3	5	4	5	7	5	3	6	5	2	6	7	4	8	12	7	14	12	15	19
	1975	5	6	8	6	8	10	8	5	9	8	4	9	11	8	13	19	12	23	19	20	28
	2000	8	11	13	9	11	14	11	8	13	12	6	13	15	12	19	26	18	32	27	27	38
m_δ	Mean	3	2	4	3	2	4	3	2	4	3	1	3	4	2	4	6	3	7	5	4	6
$m_{\mu\delta}$	epoch	11	7	13	12	5	13	12	6	13	13	5	14	18	8	20	28	10	30	25	13	28
m_δ	1925	3	2	4	3	2	4	3	2	4	3	1	3	4	2	5	7	3	7	6	4	7
	1950	5	3	6	5	2	6	5	3	6	5	2	6	7	4	8	12	5	13	10	5	12
	1975	7	4	8	8	3	8	8	4	9	8	4	9	11	6	13	18	8	19	16	8	18
	2000	10	6	11	11	4	11	11	5	12	11	5	12	16	8	18	25	10	27	22	11	24

catalogue – they usually are noted as general catalogues.

A distinction should be made between the derived catalogues, constructed according to strict criteria, and so-called survey catalogues, containing approximate coordinates (thus not on one and the same system) of a multitude of stars. A well known example is the „Bonner Durchmusterung" (designation: BD), giving positions of 324 188 stars, between -2^{o} and $+90^{o}$ declinations, for the epoch 1855.0.

In the derived catalogues, almost without exception, the equinox and epoch are the same. Furthermore, unlike observational catalogues, these catalogues contain data which enable one to compute stellar coordinates for whatever moment is desired, differing from that for which the catalogue is given.

5.1. Bessel (1830) was the first to construct a serious derived catalogue of the fundamental type. Since the several catalogues of this type have been compiled, with more or less success. At different times there have been different catalogues considered fundamental (Bakulin, 1949; Rybka, 1974). The purpose of such a fundamental catalogue is to embody the approximation of an ideal inertial coordinate system, free from all but rectilinear and uniform motion through space.

In 1879 Auwers initiated a series of fundamental catalogues, the fourth edition of which – with the designation FK4 – is the present fundamental catalogue (which the International Astronomical Union officially adopted in 1961). The first of these catalogues, „Fundamental-Catalog für die Zonen-Beobachtungen am nördlichen Himmel" (designation FC), contained data for 539 stars in the northern sky. It was followed by NFK („Neuer Fundamentalkatalog", 1907), containing 927 stars of the whole sky. In 1937 and 1938 there appeared FK3 („Dritter Fundamentalkatalog"), expanded to 1535 stars. Finally, in 1963 FK4 („Fourth Fundamental Catalogue") has been issued as an important creation of Fricke and Koppf (1963) and their assotiates. The number of stars in this catalogue did not change: it remained at 1535.

We present this information in order to point out the developing path of construction of a fundamental system – a path requiring a lot of work and skill.

The present mean characteristics of the FK4 is best represented by the Table 2, given by Lederle (1976). It contains individual, systematic and total errors. The individual errors bear an accidental character and they are derived from the observational data for every star separately (given in the catalogue). Theoretically, systematic errors are inferred from the dispersion of the fundamental system related to an ideal inertial system – but in fact they are derived from the dispersion of the system of the observational absolute catalogues. The two errors are averaged for the given sky region and so total errors are obtained.

Table 4 is also due to Lederle (1976) and contains upper errors by particular declinations. Here again, as in the preceding Table 2, a difference in the precision between northern and southern sky is apparent as well as a distinction in the precision between α and δ systems in the southern hemisphere – in favour of declinations. From the observation in Chile (Anguita, 1974) it follows that the declination system of FK4 is to a great extent more real than the α system. It has been shown that in this hemisphere FK4 is affected by substantial systematic errors of type

What is to be said about FK4? In addition to those deficiencies just cited (errors amounting to 0."1 in both coordinates; higher accuracy of the declination system than that of the right ascension system; regional inhomogeneity; the precision attained in the northern hemisphere higher than that reached in the southern hemisphere) two more can be added: an insufficient number of stars and a lack of stars fainter than 7.5 magnitude (Fricke, Gliese, 1968.) The latter two are especia... ... in particular nowadays when the need to include (in astrometrical works) as many ... stars as possible is urgent. It is to be noted at this juncture that the extension of th... fundamental system to embrace faint stars in the past has been prevented, as to a great extent is the case at the present time, by the optical capacity of the meridian instruments, bad astroclimatic conditions as well as by the observing programs themselves, the latter having favored bright stars.

5.2. From the rest of fundamental catalogues now in use we mention with a few words only two: those designated by GC and N30.

The „Albany General Catalogue" (designation GC), issued in 1937, is a result of thirty years work of Lewis and Benjamin Boss. It contains 33 342 stars - including almost all stars down to 7.0 magnitude, as well as a few thousand fainter stars - for the epoch and equinox 1950.0. The catalogue is of unequal character in its contents - with regard to its internal accuracy and consistency of the system as such (Podobed, 1968d; Fricke, 1972). Two thirds of the stars are represented by coordinates with a mean error $\pm 0\overset{''}{.}45$, growing with the time. The bright star system differs from that of the faint stars. It follows from an analysis (Brosche et al., 1964) that the mean systematic differences FK4-GC for 1950 lie within the limits:

$$-0\overset{s}{.}032 < \Delta\alpha \cos \quad [-(\Delta\alpha_{\alpha} + \Delta\alpha_{\delta}) \cos \quad] < +0\overset{s}{.}038$$
$$-0\overset{''}{.}16 < \Delta\delta \quad [-(\Delta\delta_{\alpha} + \Delta\delta_{\delta})] < +0\overset{''}{.}39$$

One of the gravest defects of this system is the unsatisfactory accuracy of the proper motions. Systematic differences of the centennial values are comprised within the limits:

$$-0\overset{s}{.}067 < \Delta\mu \cos \quad [-(\Delta\mu_{\alpha} + \Delta\mu_{\delta}) < +0\overset{s}{.}078$$
$$-0\overset{''}{.}27 < \Delta\mu' \quad [-(\Delta\mu'_{\alpha} + \Delta\mu'_{\delta})] < +0\overset{''}{.}69$$

This comparison cannot be considered as having a general value because they are related to only a restricted number of stars, figuring also in the FK4 catalogue. Accordingly, Fricke (1972) is right to qualify this catalogue as not fundamental but only as a primary reference frame. There is a desire for a complete revision of this catalogue (Brouwer, 1960), but this has not yet achieved.

Morgan's catalogue N30 („Catalog of 5268 Standard Stars, Based on the Normal System N30", 1952) contains a considerably smaller number of stars than GC (more uniformly distributed throughout the sky), but it still represents on a small scale an improved version of the GC catalogue. On the basis of 70 catalogues (about thirty of them being absolute) with mean epochs from 1920.0 to 1950.0, not used for GC, and relying upon a corrected GC system, Morgan has formed his own catalogue (Podobed, 1968d; Fricke, 1972). Individual catalogue errors are only slightly less than in the GC, but with regard to systematic errors there is a better accordance between N30 and FK4.

According to Brosche et al. (1964), mean systematic differences FK4-N30 for 1950 are:

$$-0^{s}.032 < \Delta\alpha \cos\delta < +0^{s}.003 \qquad -0''.23 < \Delta\delta < +0''.21$$
$$-0^{s}.088 < \Delta\mu \cos\delta < +0^{s}.034 \qquad -0''.70 < \Delta\mu' < +0''.58$$

Proper motions $\Delta\mu \cos\delta$ and $\Delta\mu'$ pertain to centennial values. Evidently, the discrepancies are not insignificant.

Concerning N30 no similar remarks could be put forward as those made on account of GC, but still this catalogue cannot compete with FK4. A revision of it and an improvement of its accuracy is necessary.

Fajemirokun (1975) has made a comparison of N30 and GC with FK4 for the epoch 1970.0 whereby some defects of these former two catalogues have been stated. He inferred that most of the systematic differences between the two catalogues might be eliminated by applying values of these differences as established by Brosche et al. (1964). In our opinion this would mean that the systematic differences for particular zones were sufficiently representative and might be applied to stars in the given zones.

5.3. As has already been observed, an important shortcoming of the FK4 is presented by the fact that it contains bright stars only. However, a basic coördinate system must rely upon faint stars as well, i.e. the need arises to know accurate positions of some faint stars too (Zverev, 1954). To mitigate that need the compilation of AGK2A was offered as a first step. But this action failed to yield the results desired (Podobed, 1968f), and so new solutions had to be looked for. As a result two projects have appeared: the KSZ and AGK3R programs.

„The Catalogue of Faint Stars" (KSZ) is an original program, of far reaching importance, initiated by Soviet astrometrists in 1932 (I Astrometrical Conference of the USSR, Pulkovo) and realized under the direction of M.S.Zverev (1954). It consists of several stages. The starting point is the composition of a fundamental catalogue (FKSZ) containing 931 stars, between 7.5 and 8.5 magnitude, with spectral classes G and K. Next, coordinates of an enlarged number of faint stars, referred to the FKSZ, should be determined - striving thereby to secure 12 stars to each 25 square degrees - visual magnitudes confined between 7.5 and 9.5 (photographic magnitudes between 8.5 and 10.0), and confined mainly to G and K spectral types. The Soviet list, between $+90^{o}$ and -30^{o} declinations, contains 15 690 stars. An extension of this program is the Program of Southern Reference Stars (SRS), containing faint stars between -5^{o} and -90^{o} declinations, compiled at the Cape Observatory. The SRS list contains all the stars figuring in the Soviet list from -5^{o} to -30^{o} declinations, completing this list by stars disposed further to the south, selected approximately according to the Soviet criterion applied to KSZ. Number of stars in this list amounts to 20 000. Concerted with this action are works aimed at the securing elements necessary for the construction of the KSZ system. The position of this coordinate system is determined by the observation of 10 bright minor planets. These stars are then related to 450 pointlike galaxies of low luminosity (to 14th magnitude). The completion of this ambitious program is expected towards the close of this century. About the works already performed the following might be said: a preliminary FKSZ (designation: PFKSZ), not yet of a fundamental character, is completed with the internal errors for 1950.0:

$$\varepsilon_{\alpha}\cos\delta = \pm 0\overset{s}{.}007 \qquad \varepsilon_{\delta} = \pm 0\overset{''}{.}13$$
$$\varepsilon_{\mu}\cos\delta = \pm 0\overset{s}{.}029 \qquad \varepsilon_{\mu'} = \pm 0\overset{''}{.}50$$

and the system as such being close to FK3 i.e. FK4 respectively (Polozhentsev, 1967) - quite understandable in view of the fact that the basic observational material has been obtained by relative methods in the FK3 system. The catalogue has subsequently been transferred into the FK4 system, receiving the designation PFKSZ'. Preparations are under way for PKSZ-2 with the expected errors:

$$\varepsilon_{\alpha}\cos\delta = \pm 0\overset{s}{.}002 \qquad \text{and} \qquad \varepsilon_{\delta} = \pm 0\overset{''}{.}04$$

(Jatskiv et al., 1974). The elaboration of FKSZ, disposing of its own system, is still prevented by the insufficient number of absolute catalogues. For the zone $+90^{\circ}$ to $+25^{\circ}$ declination observations of the selected galaxies are completed, the first epoch of observation being thereby completed. The completion of the southern declination zone still lies ahead. An immense number of selected minor planet observations has been carried out, but their utilization in the fundamental astrometry is lagging behind - for many reasons (see Chapter 4.3), the lack of sufficiently accurate positions of the reference stars (Orel'skaya, 1967; Zverev, 1967), being one of them. The observations of the north and south (SRS) programs in the first epoch are closing completion. As is evident, the task is complex one and requires more time for full realisation.

The AGK3R program, conducted by Washington astronomers, has, by its conception, been less ambitious than KSZ but it was aimed at a speedy satisfing of a need. Here are some informations.

The second photographic star catalogue (AGK2) of the German Astronomische Gesellschaft (AG) contains 183 520 northern faint stars for the mean epoch 1930. The coordinates are derived taking AGK2A as reference system, the latter containing coordinates of 13 747 stars in the FK3 system.

Some twenty years ago it was decided to compile a new catalogue, AGK3, but this required previous forming of a new reference catalogue. In this way the AGK3R program of 21 499 stars (from -5° to $+90^{\circ}$, with magnitudes from 6.9 to 9.2) was created, including all KSZ and FKSZ programs stars. The star coordinates in the FK4 system have the following internal accuracy:

$$\varepsilon_{\alpha}\cos\delta = \pm 0\overset{s}{.}005 \qquad \text{and} \qquad \varepsilon_{\delta} = \pm 0\overset{''}{.}116.$$

Magnitude effects in the catalogue are negligible (Schombert, Corbin, 1974). Polozhentsev and Kurianova (1975) have compared the PFKSZ' and AGK3R systems stating that their systems are close to each other, particularly in right ascension.

A photographic catalogue AGK3 of high precision has been elaborated (mean error $\pm 0\overset{''}{.}16$ in both coordinates and $\pm 0\overset{''}{.}80$ in the centennial proper motions) which are less than in the FK4 (Fricke, 1972).

By analogy with the AGK3 for the northern hemisphere, a similar catalogue, according to a program of the Cape-Sydney-Yale observatories, is being created for the southern hemisphere, SRS stars presenting the necessary reference system. The work is not yet completed.

5.4. There exists a difference between the positions systems of bright and faint stars and it is therefore useful to connect them with one and the same instrument. The declination catalogue of Korol' (1969), combining in one entity 1181 bright (from FK3 and Pulkovo catalogues) and 611 faint stars (from FKSZ) is an example. The analysis of these data reveals the difficulties in connecting, but the basic problem arises from the limited light power of the present day astrometrical instruments, not well suited for the observation of faint stars (Zverev, Nemiro, 1957).

It is therefore understandable that it is not an easy task to construct a catalogue of high accuracy combining a large number of faint and bright stars. This has been found once more, when compiling the SAO catalogue (1966).

The nonexistence of a homogeneous catalogue, comprising the entire sky, had been sharply felt in particular in observing the artificial satellites. In consequence, it has been resolved at the Smithsonian Astrophysical Observatory (SAO) to compose a catalogue which would meet the following criteria: a) the coordinates given in a homogeneous system; b) each square degree to dispose of at least four stars; c) the system must be spread over the whole sky; d) standard coordinate errors should not exceed 1"; e) proper motions of all selected stars ought to be known; f) equator and equinox to be refered to 1950.0; g) the catalogue form to be adopted for computer use too.

These criteria are met by the „SAO Star Catalogue" with 258 997 stars in FK4 system. Stars between -2 and +14 magnitudes are comprised, those of a low luminosity (between 8th and 10th magnitudes) being, naturally, the most numerous, making 82% of the catalogue. Standard coordinate deviation, for the epoch 1963.5, is on the average $0\overset{''}{.}5$. (Haramundanis, 1967), a not a small value, but in view of the heterogenity of the material from which the catalogue has been composed, the result is to be judged as good one. As the accuracy is deteriorating with the time, the catalogue needs an improvement by new observations, new treatment, etc.

5.5 In the preceding chapters informations are given about several derived catalogues, some of them being fundamental. We are now going to mention a few more of them.

In 1948 a catalogue of 2957 geodetical stars (KGZ) has been published (Cimmermann, 1948). Its accuracy, very high at beginning, diminished from year to year. The revised catalogue of these stars (KGZ2) has been issued in 1968 (Trudy CNIIGAiK, 179).

A general catalogue of Melchior and Dejaiffe (1969) contains declinations and proper motions of 404 stars of the International Latitude Service programs, derived on the basis of 11 501 data taken from various catalogues, issued from 1745 to 1963. Internal errors are:

$$\varepsilon_\delta = \pm 0\overset{''}{.}062 \qquad \text{and} \qquad \varepsilon_\mu = \pm 0\overset{''}{.}19$$

Declinations for the same stars have been calculated (Sadzhakov, Shaletich, 1975) by using meridian catalogues from 1929 to 1972, i.e. catalogues published in more recent years. Internal érrors are:

$$\varepsilon_\delta - \pm 0''.071 \qquad \text{and} \qquad \varepsilon_\mu - \pm 0''.23.$$

The elaboration of the catalogue of 1717 of the PZT northern stars programs is under way. A general catalogue resulting from the observations at 11 observatories may be expected in the early 1980's (Yasuda, 1976).

These and other derived catalogues, adapted for use in geodetic astronomy and for the study of the Earth's rotation (rate of rotation, polar motions) are an important contribution to fundamental astrometry, but owing to their relatively low accuracy, they cannot satisfy other needs, in particular if we are to deal with measures of highest precision (Teleki, 1966). The precision even of the best of them, that of FK4, cannot meet demands of the time and latitude services. It is therefore understandable that these services are induced to seek an improvement of their results by internal smoothing. The so-called declination corrections, derived from latitude measures, are so heterogeneous by nature, that hitherto they could not be used for the correction of stellar catalogues – to bring this about it is necessary to free these corrections, to the greatest possible extent, from the factors having no connection with the stellar coordinates. Should this prove possible – as is the case in the time services – then catalogues of a satisfactory precision can be derived from direct measurements. There are several catalogues derived from the time services data, beginning with Pavlov's preliminary general catalogue (1961), composed on the basis of observations with the photo-electric transit instrument. The internal accuracy of these catalogues is high (Guinot, 1961). From 185 371 observations with small transit instruments at 9 Soviet observatories, Afanas'eva et al (1966) have derived a general catalogue of right ascensions of 807 stars. Mean catalogue epoch is 1958.0. Mean errors of catalogue positions are:

$$\pm 0^s.0025\ (-10^\circ < \delta < 18^\circ),\ \pm 0^s.0022\ (20^\circ < \delta < 40^\circ)\ \text{and}\ \pm 0^s.0037\ (55^\circ < \delta < 76^\circ).$$

Nemiro and Medvedeva (Nemiro, 1970) have derived proper motions for the stars of this catalogue, independent of those obtained from fundamental catalogues.

Apart from general catalogues composed from observational catalogues obtained with different instruments, there are also catalogues composed from long series of observations carried out with one and the same instrument. Two important catalogues by Nemiro (1958), derived from long observational series extended over a century with the Pulkovo Large Transit Instrument might be taken as an example. We have in view two catalogues of right ascensions (Pu α 1 and Pu α 2), comparable by their accuracy with FK3 and N30.

6. Proper motions

The determination of stellar proper motions presents one of the most difficult problems in fundamental astrometry. Their values are extremely small, and thus long series of observations for their determination are necessary. Old measures must be used along with the most recent ones. But the precision of old observations is very often not comparable with the modern ones – and there we have once more the problem of connecting the old and the new observations, indicated earlier (Chapter 1). One should be aware of the fact that the secular instrument's system variation introduces an appreciable error in the proper motion system (Gliese, 1965).

Proper motions might be classified in three groups (Stoy, 1975):

a) Relative – deductible from photographies obtained with the same or similar instruments at different epochs. The procedure is suitable only if proper motions are large; the effect of the measuring errors then losing its significance.

b) Fundamental – derived from the stellar positions obtained with meridian instruments or photographs, with reference to stars with well known positions.

c) Absolute – determined, theoretically, with reference to an absolute coordinate system but in fact only relatively with reference to selected extragalactic nebulae, whose proper motions are considered negligible.

Of particular importance are the last two proper-motion systems, so differing among themselves that their treatment should be carried out quite separately (Vasilevskis, 1967). The two systems might be defined in the following way (Fricke, 1972). The fundamental proper motions μ_F might be represented in the form:

$$\mu_F = \mu_\odot + \mu_{syst} + \mu_{pec} + \mu_{prec} + \mu_{\sigma(F)}$$

while absolute ones, with reference to galaxies:

$$\mu_G = \mu_\odot + \mu_{syst} + \mu_{pec} + \mu_{\sigma(G)}$$

where:

$\mu_\odot$ - effect of the Sun's motion,
μ_{syst} - effect of the systematic stellar motion (galactic rotation included),
μ_{pec} - residual motion of particular star,
μ_{prec} - effect of the incorrect precession value,
$\mu_{\sigma(F)}$ and $\mu_{\sigma(G)}$ - sums of corresponding systematic and accidental errors.

From these two equations we obtain:

$$\Delta\mu = \mu_F - \mu_G = \mu_{prec} + \mu_{\sigma(F)} - \mu_{\sigma(G)}$$

meaning that precessional error is the main source of the difference, presenting a a possibility to determine it from $\Delta\mu$.

Table 2 gives information about the precision of proper motion of stars contained in FK4 catalogue. As can be seen, the mean standard error of the centennial value of the proper motion of all stars is ±0".24 in right ascension and ±0".18 in declination. If the northern and southern sky are taken separately a great difference in the precision can be noticed, the preference belonging again to the northern hemisphere.

In Chapter 5.2 some characteristics of proper motions of the GC and N30 systems have been pointed out. By comparing proper motions systems of FK3, N30 and FK4, Fricke (1972) arrives at the following conclusions:

a) proper motions in declination - in the region from -20° to $+90^{\circ}$ declination the systems do not show any considerable differences, which speaks in favour of the reality of these data. South of -20° the differences are already substantial, larger than calculated systematic errors.

b) proper motions in right ascension - the differences are pronounced and are correlated with the stellar magnitudes.

It can be generally stated that the mean square error of determination of annual proper motion values in the fundamental catalogues (FK4, GC, N30) for bright stars is of the order of thousandth and for the faint stars of the order of hundreth of arc second (Podobed, 1968). In other catalogues the accuracy of these values is noticeable smaller.

There are two programs according to which the determination of absolute proper motions is carried out with reference to the pointlike galaxies: the Pulkovo and Lick programmes (Podobed, Nestorov, 1975). Pulkovo program comprises galaxies down to the 14th magnitude, while that of Lick down to 16th magnitude. The Lick program for the northern sky is practically completed, and the first photographic records for the southern sky are obtained. The Pulkovo program is practically completed for the northern and partially for the southern sky. The accuracy of a single centenniel value of absolute proper motion is: for reference stars $\pm 0\overset{''}{.}52$, for AGK3R stars $\pm 0\overset{''}{.}70$ and for galaxies $\pm 0\overset{''}{.}62$ (Fatchikin, 1968), the determination being performed through comparison of two photographic plates taken at epochs 22.4 years apart. In the Lick program, for an epoch difference of 19.2 years, a value of $\pm 0\overset{''}{.}7$ (for stars) has been obtained (Klemola et al., 1971). These errors are not small and it is only with the time that more precise values might be expected. Otherwise, proper motions in declination in both systems are in good agreement among themselves and with the fundamental system, but they disagree in right ascension – by more than 1" for a century – their mean values being, however, in good accordance with the fundamental $\mu'(\alpha)$ (Fricke, 1974).

On the basis of $\Delta\mu$ thus obtained, corrections have been derived of luni-solar precession ($\Delta p1$), of planetary precession ($\Delta q1$) and of Newcomb's precession (Δe). In the following Table 5 (Podobed, Nesterov, 1975) a survey is presented of the values derived from the observations of galaxies, as well as results obtained from nongalactic data. A rather large dispersion of results is evident, pointing to the existing difficulties.

Looking at the present situation realistically, we have to note that we still are far away from the solution of the problem of proper motions. The multitude of stars requires a length of time and, in addition, we are compelled to enhance conti-

Table 5. Corrections of Newcomb's luni-solar precession $100\Delta p_1$ and the values $\Delta E = \Delta q_1 + \Delta e$, on the basis of several authors determinations (Podobed, Nesterov, 1975, p.201).

Authors	100 Δ p_1	100 Δ E	Data
Wilson, Reimond	+0″94 ±0″04	+1″10 ±0″04	Catalogue GC
Oort	+1.11 ±0.07	+1.14 ±0.07	Catalogue FK3
Williams,Vyssotsky	+1.31 ±0.07	+1.64 ±0.07	Catalogue FK3
Morgan, Oort	+0.75	+1.09′	System of 512 distant FK4 stars
Fricke	+1.10 ±0.10	+1.20 ±0.11	
Dieckvoss	+1.27 ±0.03	+1.49 ±0.03	160 000 AGK3 stars
Fatchikin	+1.04 ±0.20	-0.53 ±0.20	779 AGK3 stars,around the galaxies
Vasilevskis,Klemola	+0.75 ±0.20	+1.21 ±0.20	2560 AGK3 stars, around the galaxies

nuously the measuring precision. Stoy's (1975) appeal for new and more efficient undertakings seems quite justified.

NEW TENDENCIES AND THE FUTURE

The IAU Symposium N°61 „New Problems in Astrometry", held in 1973 in Perth, has put forward the following conclusion (see Proceedings of that symposium, p. 335): „This Symposium recognizes the inadequacy of the existing optical astrometric data to meet modern requirements for precision positions and proper motions. It therefore urges that the great accuracy of radio positions and the potentiality of new optical and space techniques should be fully exploited". This statement in no case seems exaggerated having regard to what has been set forth in the preceding chapters and knowing the existing needs.

Fortunately, there seem to be ways out from this rather difficult situation, lasting for so long. The points, insisted upon in the foregoing conclusion, have already given results, and it is therefore with optimism that the future is looked at.

Now we are going to present, in brief, those new ways, wbich justify our optimism. We will divide them into three groups: classical optical astrometry, radio--astrometry and space astrometry. At the end the plans for the elaboration of FK5 will be set out.

7. Classical optical astrometry

7.1. Pavlov (1963) has set forth the following demands for the construction of transit instrument of a rational type: symmetry (not only geometrical and mechanical but thermical also), stability, differentiality (instrumental errors affect the final result differentially only), precise determination of the level error as well as the protection of the instrument from the outside influences. An instrument, satisfying maximally these demands, has been constructed (Pavlov, 1972) and mounted in a pavillion, which ensures open air conditions, high over the neighboring ground (about three meters).

This example has been cited in order to illustrate the need for taking complex measures - simultaneous solutions of diverse problems, affecting observational results. Thus, if a considerable improvement of accuracy is desired, than one has to strugle simultaneously against instrumental defects and negative influences originating from the surroundings and for the improvement of methods of observation and their treatment, etc. Such an all-inclusive plan has been forwarded by Høg (1974). Evidently, this is not always possible, so we have to be content with partial solutions.

Table 3 presents the possibilities of various micrometers. A considerable improvement in the precision is attained with the introduction of modern micrometers. It is important that possibility be given for observation of considerable fainter stars than at present and that daily observations could also be made.

Side by side with this metal circles have been replaced by glass circles, their reading has been made automatic, a general stabilisation of the instrument has been achieved as well as automatisation of the observations and their treatment. All this resulted in jump-like changes of the precision. Let us return to the Table 1, and take data relating to the Perth meridian circle. Prior to the modernisation it yielded results of the usual precision (see results pertaining to Bergedorf, where this instrument was earlier located), but after the modernisation the errors have been reduced by a third of their previous value. Not only that (Høg, 1974): for sixty years of work in Bergedorf the number of observations was about 130 000, whereas in only one tenth of that time in Perth the number of observations of a statistical weight of 200 000 has been achieved (for technical reasons a fourth of clear nights could not be used for observation). Thus modernisation and automatisation have resulted not only in the improvement of the internal precision but have considerable enhanced the output. The observer is excluded and thus, at a stroke, that variable personal error has been eliminated.

This experience is in itself sufficient to recommend modernisation of old instruments. Still greater advance than that achieved with the Bergedorf instrument might be rightly expected in the future.

The U.S. Naval Observatory in Washington has reconstructed in 1972 its old meridian circle. A new objective compensating for temperature has been mounted, as well as new glass circles and an angle reading system (Klock, 1976). Simultaneously a new instrument, the ATC (Automatic Transit Circle) with a modified Cassegrain system is being put into operation (Klock, 1967; Gauss, 1974).

Tokyo Observatory has ordered a new photo-electric, automatic meridian circle (of classical type). According to H.Yasuda, this instrument should make possible observation of stars and members of the solar system down to 11th magnitude. It has particularly been required that systematic errors, connected with the instrumental stabilisation, should be separable from those originating from local meteorological factors. The precision of observation is expected to be equal in all declination zones.

Side by side with the modernisation of old and the construction of new standard type instruments, instruments of a quite new conception are begining to appear.

We have already mentioned the fine qualities of the Danjon astrolabe (see Chapter 4.4) and modern small transit instruments (Chapter 5.5) pointing out their utilisation for the catalogue work - especially if observations with astrolabes will be automatic. The utilisation of small instruments is of particular interest as they do not suffer from the deficiencies inherent in large instruments. Zverev's photographic vertical circle (1960) is small, and already yields fine results (mean error of a single measurements is $\pm 0''.25$) (Zverev et al., 1969), even better results being expected after its reconstruction.

The observations with the zenith-telescope are very suitable for the determination of stellar declinations (Drozdov, 1975). The internal precision is about $\pm$ $0''.20$ for a single observation. Such observations should therefore be intensified.

The greatest advance is expected from the horizontal meridian instruments - their development is connected with the names of R.d'E. Atkinson (1947) and L.A. Suharev (1948). The Suharev Pulkovo Horizontal Circle is mounted in a housing of special design and with a good foundation. The only movable part is a mirror with its axis (30 cm in diameter) both cast in one steel block. The light rays are reflected from this mirror into fixed tubes (bearing an objective 190/4200 mm), specially protected against temperature changes. So far only preliminary results in the observing of right ascensions are to hand (Pinigin, 1975): mean error of a single determination of right ascension at upper transit is $\pm 0^s.011$ cos and $\pm 0^s.013$ cos at lower transits. Better results are expected from the final version of the instrument not only in right ascension, but in declination also.

Høg (1973a) is developing a horizontal type of meridian circle and gives plans for the construction of a new type of this instrument (GMC). The advantages of this are: a slight flexure (about $0''.02$), relative simplicity and small size. The instrument is to be housed in a special pavilion, designed so as to reduce refraction disturbances (Høg, 1973b).

Høg (1974) has compared characteristics of the ATC and two horizontal meridian circles (Atkinson's and Suharev's) with those proper to his own GMC, and has drawn the following conclusions: the shortcoming of ATC is its complicated optical-mechanical system while its adventage is presented by its automatic operation controlled by a computer. The problems of Atkinson's instrument are refractional and seeing disturbances of the light rays along extended horizontal paths; unreliability in the linkages of the mirror, circle and axis (this has subsequently been solved); two telescopes are necessary to cover the whole sky (in declination); horizontal instruments prevent the use the meridian marks; different parts of the mirror are used for different declinations; the precision of circle reading must be high. On the Suharev's instrument the axis-mirror linkage problem has been properly solved (made out of single steel piece). The GMC is the simplest of them all, and consequently has the fewest instrumental problems.

What a precision is to be expected from the new instruments? Høg (1974) anticipates an accuracy of 0"05 in the determination of faint stars positions down to 11-12th magnitude with the conventional meridian circles. Suharev (private comunication) is expecting from his instrument a precision of a few hundredths of arc seconds in both coordinates. One is entitled, therefore to anticipate an internal error of azimuthal instruments to be under 0"1, which would represent a great advance.

A high precision is to be expected from the new Pulkovo transit instrument designed for the determination of absolute right ascensions, now under construction to a scheme given by Nemiro (1960). The instrument is consisting of a central pentag and two long-focal tubes, maunted horizontally along the first vertical. The advantages of this instrument: results do not depend from the pivot irregularities and from temperature influence on instrument tube, the invariability of the pentag-angle is necessary for the duration only of the observation of a star, meridian marks are not necessary nor the adjustment of the axes, there is also possibility for automatisation of the observation. The disadvantages: more pronounced temperature effects, the exigencies regarding position of mirrors are severe, the instrument is extended over a large area.

Høg (1975) has made some estimation regarding prospective increase of the output of the future meridian circles. If the annual weight of the present-time visual meridian circle is taken as unit, then the photoelectric circle is evaluated as 15, horizontal circle as 40, a horizontal circle in exceptionally good wheather conditions as 800. Should this progress be accomplished, then Tucker's forecast (1969) that meridian circles will continue their work in the next 50-100 years might be resonably accepted.

7.2. The progress is, naturally not limited only to the instruments as observing tools, but to the accessories attached to them as well. We have in view, in the first place, the equipment for the registration of the observing data and for their processing where significant results at the present time are achieved.

We would like to point out especially the equipment connected with the use of the meridian marks (Mitić, 1975). The readings of the marks are invested with problems, considerably diminishing the precision of right ascensions determinations. In order to eliminate these defects, measures are proposed to protect the marks' pillars (Suharev, 1957), and to eliminate refraction disturbances. For the latter two suggestions have been proposed: a) insertion of vacuum tubes between the instrument and the marks (van Herk, de Munck, 1954), and b) insertion of double tubes (with no vacuum), securing air circulation between the outer and inner tubes (Suharev, 1957). The variant a) has been realized, according to a project of Mitić, at the Belgrade Observatory, and has yielded excellent results (Mitić, Pakvor, 1977): mean error of a single reading of the mark is $\pm 0^s.005$. It is important to notice that a special attention has been paid to the contruction and protection of mark pillars.

7.3. The role of the equatorial instruments in the fundamental astrometry is steadily increasing and a need is imposed to improve their precision. The accuracy of the photographic positions in the sense of accidental errors depends on the following factors (Podobed, 1968): focal length of the astrograph, quality of the astronegatives, measuring errors, number of reference stars and accuracy of their coordinates. The mean error of a star position, under the present conditions, lies between 0.″1 and 0.″2.

Considering the factors causing errors in the astrographic observations, it is indisputable that a substantial improvement of the precision is possible, which is also expected.

7.4. Little attention has been paid so far to the site selection for instruments of azimuthal mounting. They are mainly located in such external conditions and mounted in such pavilions, that observational results are sensibly affected. One is therefore impressed by the procedure applied with the site selection for the new French astrometric observatory CERGA (Kovalevsky, 1974), whereby systematic investigation of the star images at different localities has been carried out (Laclare, 1974). This observatory is built at an altitude of 1300 meters. It is also planned to install an automatic meridian circle in the Canary Islands, as a Danish-British cooperative undertaking. A careful exploration has shown that excellent astroclimatic conditions prevailed there in the highground, at an altitude of 2366 meters, giving good prospects for more accurate astrometric results, at the same time creating possibilities for a considerable increase in the output of the meridian circle (Høg, 1975).

The sites with greater altitudes, with cleaner atmosphere, are desirable. The calculation of the refractional effects being impossible, a preventive is therefore to be favored (Teleki, 1974a): the pavilions should be located on flat ground, covered with grass (possible with bush), where air circulation is good; light material is to be preferred in the pavilion contruction; the pavilion should be symmetric in shape; it is also preferable to have pavilion walls dropped during observation while the protection of the instrument should be ensured by a screen; the pavilion should be at a sufficient distance from other buildings and from cities; the instrument should be elevated above the surroundings ground in order to diminish the image trembling (Pavlov, 1963). For the elimination of the refraction fluctuations, Kolchinskij (1975) suggests similar counter-measures: the selection of locations with small image motions; the instrument should be mounted at greater altitudes and within a homogenous temperature field. One gets thus a simpler field of meteorological elements, easier to be studied and its effects to be accounted for.

Observatories placed at greater altitudes render possible more precise observations under daily conditions.

7.5. New methods are being introduced with the purpose of investigating some hitherto neglected aspects. Besides meridian methods, the method of equal altitudes has also acquired recognition. The two methods are comparable among themselves with regard to precision.

Petrov (1974) has suggested observation during polar nights, in geographic latitudes $\varphi \approx 80^{\circ}$ in order to achieve, on the basis of prolonged observational series, a higher precision in the determination of absolute azimuth (or Bessel constant n) and better right ascension corrections of clock stars in the reference catalogue. Such observations have already began at Spitzbergen ($\varphi - 78^{\circ}$) and the series lasting over 24 hours (even up to 40 hours), which certainly will yield contribution to the study of the right ascension system.

Another Soviet expedition is planed, but it will be located in the equator region. Krejnin and Murri (1972) suggest the determination of absolute declinations of equatorial stars from a place with latitude close to 0^o. Only small angles have to be measured: vertical angles in the meridian plane and horizontal ones in the vicinity of the prime vertical, with an instrument reversible through 180^o. This is best achieved with two instruments: zenith telescope, for the determination of latitude by Talcott--method, and a small transit instrument, for measuring small horizontal angles between the star's transits over the same almucantar, on both sides of the zenith ($z \approx 80^o$). The method does not require the knowledge of collimation, absolute values of latitude and azimuth. It is presumed that this method renders possible the determination of absolute declinations with an accuracy of ±0"16.

The same authors (Krejnin, Murri, 1975) suggest an absolute declination system to be composed with the aid of astrolabe, by making use of absolute declinations, determined by the previous method. It is expected that the errors of declination determination be less than ±0".1.

Gubanov (1975a) is proposing organization of special observations with the astrolabe, also in the equatorial region, for the determination of the absolute orientation of the right ascension system. The same author (1975b) has elaborated a method for the determination of absolute stellar coordinates on the basis of group observations with transit instrument and astrolabe. This has the advantage that meridian marks and levels become unnecessary, the collimation being the only error having to be accounted for.

We should mention the endeavours aimed at the improvement of the precision of determination of ΔA and ΔD, where difficulties are considerable (see Chapter 4.3). Several suggestions have been advanced for the use of artificial satellites for that purpose (Duma, 1975). These give the possibility of an increase in the precision of the determination of these quantities.

In connection with this, as well as with many other questions, it is of interest to stress Zverev's words (1976): given the possibility of an important and intricate problem to be independently resolved on the basis of different principles and by utilizing different means, all methods and means should be applied to secure the utmost accuracy of the solution of the problem.

7.6. The so-called subjective factor should, in principle, be excluded from the data treatment. In this respect relatively little has been achieved in the producing of observational catalogues and considerably more in the comparison and compiling of combined systems.

Catalogue coordinates of stars are affected by accidental and systematic errors which should be studied when forming derived catalogues. On that basis a weight is to be attached to each given catalogue (Kurianova, Fedorov, 1972). These errors cannot be found out in their pure form but only through the comparison of different catalogues. It is a problem to separate the systematic from accidental errors, an operation which in earlier times, and even nowadays, has been performed often in a subjective way. Brosche (1966 and 1970) has given a method by which catalogue differences are expressed by a sum of spherical harmonic functions, whereby systematic and accidental errors are separated more objectively. At the same time this method makes possible the study of the error sources, representing the systematic errors in two-dimensional form. This method has subsequently been further developed by Jatskiv and his associates in Kiev. The basic problem and its solutions are presented in a paper by Jatskiv and Kurjanova (1975).

Accordingly, an objective possibility is at hand to analyse systematic and accidental catalogue errors and to eliminate or reduce them.

8. Radio astrometry

8.1. Radioastrometric determination of radio sources positions has even until recently been quite uncertain, but in the last few years its accuracy has so much been increased that a new astrometric branch has come into being. The objectives of this branch are defined by Elsmore (1974) in the following way: „The application of radio astronomy techniques to establish an astrometric system based on extragalctic radio sources has important consequences both in radio astronomy and in optical astrometry. In radio astronomy it will provide a reference frame of high accuracy for source catalogues and for the calibration of instruments of positional measurements. In optical astrometry, a comparison between the positions of compact extragalactic objects determined by radio and optical methods may lead to a reduction in the errors in fundamental optical catalogues that arise from effects due to proper motion of individual stars and of galactic rotation, and hence, to the elimination of large scale inhomogeneities (Fricke, 1972)".

As is evident from the foregoing, the radio and optical astrometry are complementary. One might argue about the greater or lesser accuracy of that or other branch, but we certainly cannot speak of greater importance of one with respect to another. An integration of the two branches is called for by a resolution of the IAU Symposium $N^{o}61$ (Perth, 1973).

8.2. Methods of radioastrometric observations along with their treatment are worked out in detail and have already been included in the university textbooks (Podobed, Nesterov, 1975).

The accuracy of the determination of point-like radio sources positions has grown gradually, sometimes by jumps, and about 1970 has attained the level of the optical measurements (Pariskij, Dravskih, 1975): in that year two radio catalogues appeared in which the radio positions of the same sources showed a better accordance among themselves than that found with the optical catalogues. The standard error is $\pm 0\overset{''}{.}35$. It has been achieved by means of radio interferometers, constructed according to the classic scheme of Michelson, with basis extending over several kilometers. The precision of these observations is increasing and has already reached a high level: in Cambridge, with a 5 km basis, an internal precision of $\pm 0\overset{''}{.}02$ has been obaitned (Ryle, Elsmore, 1973).

The future, however, belongs not to these shortbased interferometers, but to those disposing of basis of several thousands kilometers (Elsmore, 1974; Counselman III, 1974; Pariskij, Dravskih, 1975). The method is still in experimental stage. Counselman III (1974) quotes a Knight's position determination of one quasar with respect to another: a value of ±0".02 for the $\Delta\alpha$ determination error and 0".08 for the mse of their declination difference has been obtained (using 8 independent observations). This precision cannot be regarded high but a precision of ±0".005 in both coordinates can be expected in near future (Counselman III, 1974), and later even ±0".001 or less (Pariskij, Dravskih, 1975), Most probably this accuracy will be proper to the relative measures for some time, but not to the absolute ones, which cannot soon attain such a high level.

Counselman III (1974) indicates the following principal error sources in the long-based measurements:

a) the radiation is due to pass through an atmosphere with changing characteristics, causing an uncertainty of about 0".04 in the measurements at stations with basis of about 4000 km. The possibility is presented to reduce this value ±0".002. The ionosphere effect amounts to 0".005 at present, but it will be reduced to a small quantity by using higher frequencies.

b) Instrumental errors (caused mainly by temperature changes) amount to 0".015 (with the basis of 4000 km), but their reduction to 0".0015 is expected.

c) Errors connected with the geophysical-astronomical model adopted along with the problems occuring in the calculation of the relative motion of antennas due to the tides of the imperfectly rigid Earth' and to the Earth rotation. These effects have not yet been definitely estimated.

Main role in the atmospheric influences is played by the air turbulence, and it is that determines the precision of the determinations from long bases (Pariskij, Dravskih, 1975). The refraction influences in these measurements are negligible if refraction effects on both antennas are equal. But they usually are not, owing to the atmosphere curvature and to the variable amounts of water vapor in the atmosphere. Even though the role played by refraction influences is smaller than the one met in the optical range, the problems of this kind occur in the radio range too (Altenhoff, 1974; Bean, Teleki, 1974).

The prospects, thus, are rather promising and it seems that the precision of radiometric measurements is going to be very high compared to the optical ones (see Chapter 7). It will also help us in the more accurate determination of astronomical constants (Walter, 1974; Elsmore, 1976; Walter, 1977).

8.3. The advantages of radio astrometry by comparison with optical astrometry are (Wade, 1974): atmospheric refraction influence is less, measurements of absolute declinations automatically referred to the Earth's instantaneous axis of rotation (observations determining diurnal arc of the source), the ability of measuring large angles with the same accuracy as small ones (this meaning that regional systematic errors are not to be expected). To this, high automatisation as well as very high working efficiency should be added.

A weak point of this method, for the moment at least, is its not being able to provide an indenpendent position of the vernal equinox, so it has to have recourse to the optical astrometry. This, probably, is only a temporary defect, an instrument being prepared in U.S.A. capable of observing brighter minor planets.

Doubtless that the possible contribution of the radio astrometry is very great (Troickij et al., 1975). The forming of a radioastrometric system with an accuracy up to 0".001 (Dravskih et al., 1975) may be expected.

8.4. Optical astrometry deals only with positions of such light sources whose radiation in the optical region of spectrum is sufficiently intense whereas radio astrometry is occupied only with radio sources. Consequently, it is necessary to find out sources, emitting sufficiently strong radiation simultaneously in one as well as in other spectral region. There are, for time being, about thirty of such subjects, of low luminosity to be sure. The comparison is therefore confined to the AGK3 system as it cannot directly be made in FK4. It should be pointed out that considerable difficulties are met with the determination of the optical positions of the radio sources (see, for instance, Murray et al., 1971).

Wade (1974) has made an analysis of the differences between optical and radio positions of these common sources. In this he has made use of Cambridge optical data in combination with the Mullard (Gr. Britain) and NRAO (U.S.A.) radio position data, obtained with short based interferometers (4.6 and 2.7 km respectively). The Table 6 gives a survey of these data. An unexpectedly good agreement among the three systems must be noted. The table is not quite conclusive, there is for instance, a dependence, in the Mullard-Optical data with right ascension, but it certainly indicative as to the possibility of high accuracy comparisons.

Table 6. Weighted mean differences of right ascensions and declinations obtained with different radio and optical instruments (Wade, 1974, p.136)

	Mullard-NRAO	Mullard-Optical	NRAO-Optical
$\Delta\alpha$	$-0^s.002 \pm 0^s.006$	$-0^s.002 \pm 0^s.005$	-
$\Delta\alpha \cos\delta$	$-0''.01 \pm 0''.07$	$-0''.01 \pm 0''.05$	$-0''.01 \pm 0''.05$
$\Delta\delta$	$-0''.08 \pm 0''.09$	$-0''.01 \pm 0''.08$	$+0''.13 \pm 0''.09$
No.of sources	7	10	10

Irrespectively of which of coordinate system is going to be primary in future – optical or radio system – on account of their mutual connection it is doubtless necessary to have optical positions of faint objects determined with more precision and their inclusion in the optical fundamental coordinate system.

9. Space astrometry

While there is an abundant experience and plenty of results in classical astrometry and while radio astrometry is growing before our eyes into an astrometric discipline with bright prospects, space astrometry, for the time being, is offering only theoretical promises; but nevertheless it might be called astrometry of the future.

This new astrometric branch is not going to eliminate classic astrometry either – at least not in the near future – but it will complement it. Here again parallel observations are necessary in order to connect old and new observational series. Such observations will make it possible for the reference system to expand from the present magnitude 7.5 to the magnitude 10 and even to the magnitude 17 (Strand, 1975; Walter, 1975). This means not only an increase in our knowledge of all astrometric data, but renders possible a better connection of the optical and radio systems.

9.1. The problems and adventages of space astrometry have been elucidated in detail at an ESRO (European Space Research Organisation) symposium at Frascati (Nguyen, Battrick, 1975) – the first of its kind – the results of which served as a basis for the ESA (European Space Agency) to outline a proposal for the launching of an astrometrical satellite (ESA, DP/PS (76), 1976).

The starting point of this project is the recognition that the accuracy of the Earth based observations is not likely to increase in the next two decades more than threefold, whereas the space astrometry is offering far-reaching improvement. The following advantages are envisaged:

- accuracy: position 0".001 to 0".003 (present 0".04 at best); proper motion: 0".001 to 0".003 per annum (three years' observations); parallax: 0".001 to 0".004 (present 0".013);
- no systematic errors as compared to present errors of 0".005 or more;
- large number of stars: 100 000, as compared to a few thausands presently observed;
- faint stars: up to magnitude 11 (or more);
- homogeneous sky coverage.

The launching is contemplated of a satellite of moderate size, weighing about 125 kg, to circle on a quasi-polar, low altitude orbit. The telescope's diameter should be about 20 cm.

This project is continuously being worked on with the consequence that new solutions are emerging, and the initial conception is undergoing changes. It is important, however, that such an astrometric spacecraft may be expected to comence operating in the early 1980's.

9.2. P.Lacroute, to whom credit is due for his pioneering work since 1967 in the development of space astrometry, summarizes in the following way the adventages of the new observational techniques (Lacroute, 1975):

a) no atmospheric refraction, and therefore no inaccurate corrections in this respect,

b) no atmospheric absorption, thus allowing observation of fainter stars,

c) no atmospheric turbulence, resulting in better images and, consequently, more accurate measurements,

d) weightlessness, which eliminates instrumental flexure.

Star positions will be related to FK4 (or, later, FK5). The question arises therefore (Bacchus, Lacroute, 1974) of the accuracy of that system, the connection of the space and classic data being dependent upon it.

9.3. NASA is preparing the launching in 1980 of a large space telescope (LST), 3 meters in diameter (van Altena et al., 1974). The presumable astrometric possibilities of the telescope are: a) an increase of the systematic precision of the FK4 (by a factor of ten) and its connection with the absolute system of radio galaxies and quasars, b) an increase by a factor of ten of the precision of parallax and proper motion determinations, as compared with the present day determinations, c) measuring of the angular diameters of stars and galactic nuclei, d) determination of separate masses through observation of over 100 spectroscopic binaries.

The expected accuracy of star positions: ±0".01 by absolute method, and ±0".002 by relative method (parallaxes, proper motions). Measuring down to 20th apparent magnitude are possible. Observations are contemplated to last 15-20 years.

This project has now reached the stage of development, and changes in the project must be reckoned with concerning construction (Fredrck, McAlister, 1975) as in the well as scheduled time of launching (expected 1983/84). The ESA will participate in the realisation of this project.

10. The elaboration of the FK5 catalogue

A fundamental coordinate system, as defined by a given stellar catalogue, must steadily be improved and it is therefore quite natural to think of a reconstruction of FK4. A summary survey of the plans for improving and extending the FK4 system is given by Fricke (1974). Following are the reasons, as stated by him, for the elaboration of a new catalogue: a) FK4 cannot satisfactorily serve more than 20 years after its composition (owing mainly to proper motions errors), b) the increase of the accuracy of modern observations and various applications need a more realistic ephemeris, c) during the last twenty years an enlarged number of absolute and relative observations of FK4 and faint stars has been made, and a solid basis is thus presented for an improvement of FK4 and its extending probably down to 9th magnitude, which might lead to the formation of new fundamental catalogue FK5. It is planed this action to complete by 1980. Most probably the catalogue will contain about 5000 stars, considerably more than FK4.

For this about 150 new catalogues will be used (published in the period after 1950), 25 of which are absolute or quasiabsolute (Gliese, 1974). Absolute catalogues, used for the elaboration of new fundamental system have to meet the following two requirements: a) the observed positions must have been determined without leaning on the stellar positions in the basic catalogue, or, should this however have been done, their systematic effect has to be eliminated by an appropriate reduction, and b) the effects of instrumental errors on the observed positions must be excluded. The first condition is usually fulfilled by only a part of the observational material, the second one never completely. The catalogues, used for the improvement of the fundamental system of positions and proper motions and satisfying the two conditions, will be treated as absolute even if they do not have their own determination of the equator and equinox.

Naturally, the data relating to ΔA and those relating to ΔD from the observations of the Sun and members of solar system will be separately analysed.

Lederle (1976), by the Table 2, points out the justification of the revision of FK4. In his opinion by means of the existing catalogues, the accuracy of the FK4 system might be considerably increased – the errors are expected to be reduced to 1/2 or 1/3.

Clearly, these expectations relate only to the stars presently in the FK4 and there is a great uncertainty what the global accuracy of the FK5 will be *after* introducing into it a large number of new stars.

A particular problem is connected with the improvement of the system for the southern sky, as that system is well in arrear with respect to the northern sky. An appreciable improvement is to be expected in the new catalogue, but Gliese (1974) is apprehensive whether there will be any improvement of the proper motions in right ascensions in the regions south of -45°.

Simultaneously with the FK5, preparations are in progress for FK5 Supplement (Fricke, 1974), which will contain an enlarged number of faint objects in the FK5 system. Among these faint objects there will be optical counterparts of the extragalactic radio sources, as well as stars in our galactic system with sensible radio emission. The positions of these objects will be obtained photographically with an accuracy of about $\pm 0\overset{s}{.}015 \cos\delta$ and $\pm 0\overset{''}{.}15$.

11. Conclusions

After a long stagnation, fundamental astrometry is advancing. An impetus to this has been presented by: improved accuracy of the classic astrometric measurements, as well as new possibilities open by radio astrometry and space astrometry. According to our present knowledge, a considerable increased accuracy of the results of fundamental astrometry might be predicted.

The question is frequently posed whether radio astrometry and space astrometry are going to eliminate the classical astrometry. In some distant future the answer might possibly be affirmative, but in near future the answer is no. The basic reasons are: verification of results obtained by new methods and the interrelating of old and the new observational series. But a maximal increase in the precision of results is required from the classical astrometry.

It is to be hoped that the fundamental astrometry will gradually develop from two-dimensional into a three-dimensional discipline, i.e. from the two-dimensional astrometry on the celestial sphere into the three-dimensional astrometry in space – using the distances of celestial bodies too. According to Gavrilov (Fedorov, 1974b), new instruments present possibility to consider a system of points in the space instead of a system of directions only. This will be an important and quantitative transition.

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